PHSX 221L **Archimedes' Principle** **Name:**______________________

Object: To study Archimedes' principle directly as well as to use it to determine quantities (such as density and specific gravity) of substances.

Theory: Archimedes' principle states that *an object placed in a fluid has an upward buoyant force on it that is equal to the weight of the fluid displaced by the object.* If an object floats in a fluid it means that it is buoyed up by a force F_b greater than or equal to its weight; if it sinks in the fluid if its weight exceeds that of the fluid it displaces. The magnitude of the buoyant force depends only on the weight of the fluid displaced by the object and does not depend on the weight of the object.

A consequence of Archimedes' (see page 466 in Serway) principle is that an object will float in a fluid if its density ρ_o is less than the density of the fluid ρ_f, and an object will sink in a fluid if its density is more than the density of the fluid, and will float in equilibrium at any submerged depth where it is placed if its density is equal to that of the fluid. Both liquids and gasses are fluids.

Using the same or similar apparatus one can also measure the specific gravity of an object, which is defined to be the ratio of its density to the density of water at the same temperature (usually 4° C). (See example 15.5 in Serway.) The term "specific gravity" might be better expressed as "relative density," but traditions are hard to change. Since specific gravity is the ratio of two densities it is unitless; and since the density of water ρ_w at 4° C is 1.000 g/cm^3 (and doesn't vary much from that over the temperature range in which water is a liquid) the specific gravity of a substance is numerically the same as its density in g/cm^3. An object's density ($\rho = m/V$) can also be measured in other ways (such as in our first lab), but the purpose here is to use Archimedes' principle.

An object more dense than water will be completely immersed when lowered into water, so the volume of the object (V_o) is the same as the volume of the water displaced by it ($V_o = V_w$) and

$$\text{sp. gr.} = \frac{\rho_o}{\rho_w} = \frac{m_o/V_o}{m_w/V_w} = \frac{m_o}{m_w} = \frac{m_o g}{m_w g} = \frac{w_o}{w_w} = \frac{w_o}{F_b} \tag{1}$$

where w_o is the weight of the object and w_w is the weight of the displaced water, and by Archimedes' principle $w_w = F_b$. If attached to a scale, the submerged object will have an apparent weight (indicated with a primed symbol) of $w'_o = w_o - F_b$. (Verify this with a free body diagram.) Thus $F_b = w_o - w'_o$ and equation 1 becomes

$$\text{sp. gr.} = \frac{w_o}{w_w} = \frac{w_o}{w_o - w'_o}, \tag{2}$$

or, in terms of mass measured on a balance (since g cancels from every term),

$$\text{sp. gr.} = \frac{m_o}{m_o - m'_o} \qquad \textit{for a heavy object that sinks}, \tag{3}$$

where m'_o is the apparent mass of the submerged object.

In order to use Archimedes' principle to determine the specific gravity of an object that floats or is less dense than water, it is necessary to use another object (a sinker) of sufficient weight and density to submerge the light object completely so that the volume of the displaced water is equal to the volume of the object. Letting the sinker hang from the light object, $w_1 = w_o + w'_s$ is the measured weight of the object and sinker with only the sinker submerged, and $w_2 = w'_o + w'_s$ is the measured weight when both are submerged. Then

$$w_1 - w_2 = (w_o + w'_s) - (w'_o + w'_s) = w_o - w'_o \tag{4}$$

or, put in terms of mass since g is constant over the experiment,

$$m_1 - m_2 = m_o - m'_o. \tag{5}$$

Substituting into equation 3 gives the specific gravity for the light object:

$$\text{sp. gr.} = \frac{m_o}{m_1 - m_2} \qquad \textit{for a light object that floats.} \tag{6}$$

Archimedes' principle can also be used to find the specific gravity of a liquid. A heavy object is weighed first in air (w_o) and then when submerged in a liquid (w'_o). Then $w_o - (w'_o)_{\text{liquid}}$ is the weight of the volume of liquid the object displaces, by Archimedes' principle. Applying the same procedure for the object in water, $w_o - (w'_o)_{\text{water}}$ is the weight of the volume of water the object displaces. Since the two volumes are the same and g is constant over the experiment, the ratio of the two weights (expressed in terms of mass) gives the specific gravity of the liquid:

$$\text{sp. gr.} = \frac{m_o - (m'_o)_{\text{liquid}}}{m_o - (m'_o)_{\text{water}}} \qquad \textit{for a liquid.} \tag{7}$$

Procedure: In each case below draw a diagram of the apparatus (see, for example, figures 15.12 and 15.23 in Serway). Also take care to avoid air bubbles on submerged objects and make sure they aren't touching the sides of the beaker. Measurements repeated three or four times help reduce errors.

Direct Proof of Archimedes' principle:

1. Fill an overflow can with water and place a beaker in position to collect overflow.

2. Hang the plummet below the bucket and measure the combined mass in air.

3. Move the overflow can below the plummet and lower the set until the plummet is immersed in the water and measure the mass again. The difference between the two weights is the buoyant force on the plummet.

4. Carefully pour the water from the beaker into the bucket; make sure no water is left in the beaker.

5. Measure the mass of the bucket (with water) and plummet to verify Archimedes principle.

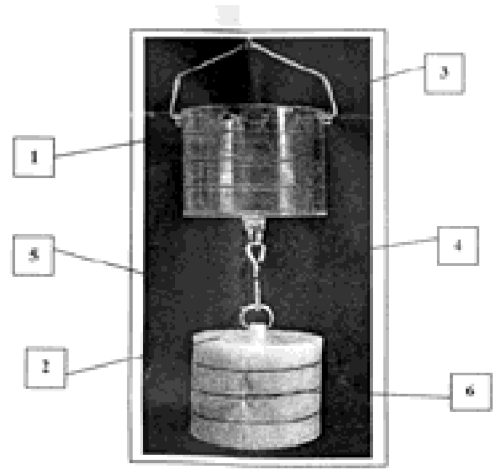

Fig.1

1 Bucket 2 Plummet 3 Handle
4 Hook 5 Ring 6 Division Mark

Specific Gravity of a Heavy Solid Object:

1. Measure the mass of a heavy object in air m_o, and the apparent mass m_o' of the same object while it is suspended by a string and completely immersed in water.

2. Use equation 3 to compute the specific gravity of the heavy object.

3. If the substance is known, compare your answer to the accepted value; if not then speculate on what the substance might be.

Specific Gravity of a Light Solid Object:

1. Measure the mass m_o of a light object alone in air. Suspend the sinker from the light object and measure the mass of the combination with only the sinker immersed in water; this is m_1. Now measure the mass of the combination with both solid objects immersed; this is m_2.

2. Use equation 6 to compute the specific gravity of the light object.

3. If the substance is known, compare your answer to the accepted value; if not then speculate on what the substance might be.

Specific Gravity of a Liquid:

1. Measure the mass of an object in air and then its apparent mass in the unknown liquid and in water. (Don't put amber in alcohol as it will dissolve.)

2. Use equation 7 to compute the specific gravity of the liquid.

3. Also use a hydrometer to measure the specific gravity of the liquid and compare your answers.

Analysis and Questions:

1. Why does a block of wood apparently lose more than its entire weight in air, when completely immersed in water? How is this possible?

2. What becomes of the lost weight of an object when immersed in a liquid? How is the apparent loss of weight explained?

3. Suppose there were a bubble of air on the bottom of the heavy object immersed in water; how would this affect the calculations of the specific gravity (or density) of the object?

4. What would the apparent weight of an object be if it were immersed in a fluid which had the same density as that of the object?

5. Does the air (which is also a fluid) produce an upward buoyant force that must be taken into account? For example, if you measure the mass of a 50 g lead sinker on a pan balance, how much upward buoyant force is exerted by the air? Does this affect the accuracy of the balance reading?

Conclusions: Summarize and evaluate this experiment.